

VERIFICATION OF TRANSLATION

I, ITOME Shigeki, a citizen of Japan, currently residing at 201 4-19-3 Senrioka-higashi, Settsu-city, Osaka, Japan, hereby declare:

That I am fully familiar with the English language and with the Japanese language in which the accompanying Japanese patent application No. 227760/2000 was prepared;

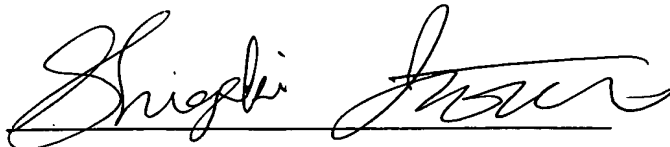
That the annexed English text is believed by me to be a true and accurate translation of the text of said Japanese patent application; and

That all statements made herein of my knowledge are true and that all statements made on information and belief are believed to be true, and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Signed at Osaka, Japan

Date: August 17, 2004

Signature:

A handwritten signature in black ink, appearing to read 'Shigeki Itome', written over a horizontal line.

ITOME Shigeki

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Kouzo OIKAWA
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[INVENTOR]
[ADDRESS OR PLACE OF ABODE]
c/o Sharp Kabushiki Kaisha
22-22, Nagaike-cho, Abeno-ku, Osaka
[NAME] Kiyoshi MINOURA
[INVENTOR]
[ADDRESS OR PLACE OF ABODE]
c/o Sharp Kabushiki Kaisha
22-22, Nagaike-cho, Abeno-ku, Osaka
[NAME] Shun UEKI
[INVENTOR]
[ADDRESS OR PLACE OF ABODE]
c/o Sharp Kabushiki Kaisha
22-22, Nagaike-cho, Abeno-ku, Osaka
[NAME] Masahiko TOMIKAWA
[PATENT APPLICANT]
[IDENTIFICATION NUMBER] 000005049
[NAME] Sharp Kabushiki Kaisha
[ATTORNEY]
[IDENTIFICATION NUMBER] 100080034
[PATENT ATTORNEY]
[NAME] kenzo HARA
[PHONE] 06-6351-4384

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[TITLE OF THE INVENTION] REFLECTIVE DISPLAY
DEVICE

[CLAIMS]

[CLAIM 1]

A reflective display device comprising a pair of substrates, a middle layer disposed between the pair of substrates, and a retro-reflector,

characterized in that a pitch of unit structures of the retro-reflector is not more than a pitch of color filters.

[CLAIM 2]

The reflective display device as set forth in claim 1, comprising a light absorbing layer for absorbing an incident ray from other pixels.

[CLAIM 3]

The reflective display device as set forth in claim 1 or 2, wherein a light absorbing element covers a side surface of a display panel.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[INDUSTRIAL FIELD OF THE INVENTION]

The present invention relates to a reflective display device such as a reflective liquid crystal display device. More specifically the present invention relates to a

reflective display device which is capable of clear multi-color display with a bright white state and a high contrast ratio without a polarizer.

[0002]

[PRIOR ART]

Liquid crystal display devices have been widely used conventionally as thin and light-weight color display devices. Among such color liquid crystal display devices, most commonly used are transmissive liquid crystal display devices which employ a back light source. The transmissive liquid crystal display devices have been used in an increasingly wider variety of field for various uses.

[0003]

What contrasts to the transmissive liquid crystal display devices are reflective liquid crystal display devices which employ other display modes, whereby reflected light of a light source is substituted for a back light. The reflective liquid crystal display devices therefore do not require a back light, thus having such features as reducing power for the light source and saving a space or weight thereof.

[0004]

That is, power consumption of the display device can be reduced as a whole, which permits the use of smaller

batteries, making the reflective liquid crystal display devices suitable for equipment which is required to be thin and light-weight. Further, given the same size or weight of the equipment, the reflective liquid crystal display devices allows the use of larger batteries, making it possible to greatly increase the operation time.

[0005]

Further, the reflective liquid crystal display devices also have advantages over other display devices in view of contrast ratio characteristics of the display. That is, in self-emitting display devices such as a CRT, a significant reduction in contrast ratio is incurred under day light outside. Such a significant reduction in contrast ratio occurs also in transmissive liquid crystal display devices, that low reflection films are coated on, when the intensity of the surrounding light is much larger than display light, as in the case under direct sun light. On the other hand, the reflective liquid crystal display devices can obtain display light which is proportional to the quantity of the surrounding light, and can avoid a reduction in contrast ratio, and therefore are suitable particularly for portable information terminals, digital video cameras, or portable video cameras, etc., which are often used outside.

[0006]

Despite such promising applications, there has been no reflective color liquid crystal display device which meets the demand for practical applications. This is chiefly due to the fact that conventional reflective color liquid crystal display devices were insufficient in terms of reflectance contrast ratio, full-color display, high-definition display, and their ability to display moving images.

[0007]

The following describes conventional reflective liquid crystal display devices in more detail. Currently, the reflective liquid crystal display devices which are widely used employ a pair of or a single polarizer. The operation modes of these liquid crystal display devices include a twist nematic mode ("TN mode" hereinafter) which performs display by controlling optical rotatory power of the liquid crystal layer by an electric field, a birefringence mode ("ECB mode" hereinafter) which performs display by controlling birefringence of the liquid crystal layer by an electric field, and a mix mode, which is a combination of the TN mode and the ECB mode.

[0008]

Meanwhile, there have been known reflective liquid crystal display devices which do not employ a polarizer.

Guest-Host-type liquid crystal elements, which incorporate a dye in liquid crystal, have been developed for this mode, which, however, had the problem of low reliability due to the addition of the dichroic dye, and the problem of low contrast ratio which is posed by the low dichroic ratio of the dye. This deficiency in contrast ratio in particular results in a significant reduction in color purity in color display using a color filter. Therefore, such reflective liquid crystal display devices which lack a contrast ratio need to be combined with a color filter having high color purity. The reflective liquid crystal display devices therefore have the problem of low brightness when the high color purity color filter is used, which spoils the advantage of high brightness of the mode which omits the polarizer.

[0009]

In order to overcome the foregoing problems, there has been developed a liquid crystal display element of a mode which employs a polymer-dispersed-type liquid crystal or a cholesteric liquid crystal, which is intended for bright and high-contrast ratio display without using a polarizer or a dye. These modes take advantage of the characteristic of the liquid crystal layer which is optically switched between a transmissive state and a scattering

state, or between a transmissive state and a reflective state, by controlling an applied voltage to the liquid crystal layer. Further, no polarizer is required in these modes and the efficiency of using light can be improved. Further, from the perspective of evaluation on color fidelity, a desirable white state can be expected in these modes compared with the TN mode or ECB mode, because the wavelength dependency is low and the problem of absorption profile of the polarizer itself, i.e., the problem of the polarizer absorbing blue light and the light transmitting through the polarizer is rendered yellow, is not posed.

[0010]

Such a mode is disclosed, for example, in Japanese Unexamined Patent Publication No. 186816/1991 (Tokukaihei 3-186816). In the liquid crystal display device in this publication, a polymer-dispersed-type liquid crystal is disposed on a black substrate, wherein a white/black state is performed by the white state, which is rendered by the scattering state of the polymer-dispersed-type liquid crystal which appears murky under no applied voltage, and by the black state, which is rendered by the transmissive state of the polymer-dispersed-type liquid crystal through which the

underlying black substrate becomes visible under applied voltage.

[0011]

USP 3,905,682, (published on September 16, 1975) discloses a liquid crystal device having a light modulator employing light scattering liquid crystal and a retro-reflector. Tokukaishou 54-105998 (published on August 20, 1979) discloses a reflective liquid crystal display device having a light modulator employing light scattering liquid crystal or guest host mode liquid crystal, a louver, and a retro-reflector. Further, USP 5,182,663 (published on January 26, 1993) discloses a liquid crystal device having a light modulator employing light scattering liquid crystal and a corner cube array.

[0012]

[PROBLEMS TO BE SOLVED BY THE INVENTION]

However, none of the foregoing conventional arrangements consider a relation between a pitch of a unit structures of a retro-reflector and a pitch of color filters. Therefore, when the color filters are provided in the foregoing arrangements, rays of incident light and outgoing light pass through different color filters, which results in reduction in luminance and chromaticity due to mixed colors.

[0013]

The foregoing problems are also common in reflective display devices in general, other than the liquid crystal display devices.

[0014]

The present invention was made in view of the foregoing problems and it is an object of the present invention to provide a reflective display device which is capable of clear multi-color display with a bright white state and a high contrast ratio, and which can prevent a reduction in luminance and chromaticity due to mixed colors.

[0015]

[MEANS TO SOLVE THE PROBLEMS]

In order to solve the foregoing problems, a reflective display device of the present invention includes a pair of substrates, a middle layer disposed between the pair of substrates, and a retro-reflector, wherein a pitch of unit structures of the retro-reflector is not more than a pitch of color filters.

[0016]

With the present invention, the light incident on the retro-reflector through any color filter is reflected by the retro-reflector and emerges from the device by passing

through the same color filter. Therefore the problem of the incident ray and the outgoing ray passing through different color filters is solved, Thus a reduction in luminance and chromaticity due to mixed colors are prevented.

[0017]

Here, the "pitch of the unit structure" of the retro-reflector is the shortest distance between corresponding positions (e.g., between vertices of corner cube array (smallest unit structure)) of adjacent corner cubes, for example, in the case of the retro-reflector of a corner cube array type, and between corresponding positions (e.g., between centers of the beads) of adjacent beads in the case of the retro-reflector of a bead (microsphere) array type.

[0018]

Further, the "pitch of the color filter sections" is the shortest distance between corresponding positions of adjacent color filter sections (e.g., between centers of the color filter sections) when the color filter sections of R (red), G (green), and B (blue) are disposed in a predetermined array pattern.

[0019]

The reflective display device of the present invention

is preferably so arranged that the incident ray from other pixels is absorbed by a light absorbing layer such as louvers or color filters. This arrangement suppresses increase in reflectance of the black state in the viewing direction, thereby realizing a desirable black state. This effect is especially notable when the retro-reflector employs the corner cube array.

[0020]

The reflective display device of the present invention is preferably so arranged that a light absorbing element covers a side surface of a display panel. This arrangement prevents entry of external light into the display panel, and also prevents adverse effects of black state, which result from scattering of light reaching the side surface by travelling inside the device. As a result, a desirable black state is realized.

[0021]

The present invention is also applicable to reflective display devices other than the reflective liquid crystal display devices.

[0022]

The middle layer is a liquid crystal layer included between the pair of substrates, in a case where the reflective display device is adapted to the reflective liquid

crystal display device. This liquid crystal layer is preferably a light scattering liquid crystal. The light scattering liquid crystal may be a polymer-dispersed-type liquid crystal, a nematic-cholesteric phase transition liquid crystal, a liquid crystal gel.

[0023]

In a mode employing a cholesteric liquid crystal (a first mode) which switches between a transmissive state and a reflecting state, or a mode employing the polymer-dispersed-type liquid crystal having holographic function (a second mode), the liquid crystal layer in the reflecting state may be rendered scattering effect by some means. That is, the liquid crystal layer is so arranged as to switch between the transmissive state and a scattered state including at least the scattering effect.

[0024]

In the first mode, the liquid crystal layer may be rendered scattering by controlling a domain size of the liquid crystal molecules. As for the second mode, scattering is rendered through exposure of scattering light. With the reflecting function, it is possible to add off-axis property to the reflective liquid crystal display device. Thus, it is possible to efficiently utilize incident rays having various incident angles.

[0025]

[EMBODIMENTS]

[First Embodiment]

The following will describe an Embodiment of the present invention with reference to Fig. 1 through Fig. 8.

[0026]

As shown in Fig. 1, a reflective liquid crystal display device 10 of this embodiment serves as a reflective display device, and includes a liquid crystal layer 1, alignment films 2 and 3, electrodes 4 and 5, an incident substrate 6, a reflection substrate 7, a color filter layer 8, and a retro-reflector 9.

[0027]

The liquid crystal layer 1 is arranged between the incident substrate 6 and the reflection substrate 7. In other words, liquid crystal is sandwiched between the incident substrate 6 and the reflection substrate 7. The liquid crystal layer 1 is a polymer-dispersed-type liquid crystal, which is one form of light scattering liquid crystal. The liquid crystal layer is fabricated by a method described later.

[0028]

The incident substrate 6 and the reflection substrate 7, so arranged as to face each other, are made of a

material such as a transparent (light-transmissive) glass plate or a transmissive polymer film. However, the reflection substrate 7 does not have to be transparent.

[0029]

The incident substrate 6 and the reflection substrate 7 respectively have the electrodes 4 and 5. The alignment films 2 and 3 have been coated on the electrodes 4 and 5, respectively. The electrodes 4 and 5 have a predetermined pattern for applying a voltage to the liquid crystal layer 1. As will be described later, the liquid crystal 1 is in a transmissive state (black state) while no voltage is applied. However, while a predetermined voltage is applied by the electrodes 4 and 5, the liquid crystal layer 1 is a scattering state (white state). It is possible to adapt light scattering liquid crystal, which turns to the scattering state while no voltage is applied, and turns to the transmissive state while the voltage is applied. Further, activematrix elements, etc. may be used to apply voltage to the electrodes 4 and 5.

[0030]

The alignment films 2 and 3 are for aligning the liquid crystal of the liquid crystal layer 1 along a predetermined direction. The alignment films 2 and 3 serves as planar alignment films, which horizontally align

the liquid crystal in the liquid crystal layer 1 (i.e. parallel to the substrates 6 and 7) while no voltage is applied.

[0031]

The color filter layer 8 is provided between the incident substrate 6 and the electrode 4. The retro-reflector 9 is provided between the reflection substrate 7 and the electrode 5.

[0032]

The color filter layer 8 is provided to realize multi-color display. The color filter layer 8 includes color filters 8R, 8G, 8B of red (R), green (G), and blue (B) which are disposed in a predetermined array pattern. Pixels are formed corresponding to the color filters 8R, 8G, and 8B.

[0033]

Between the color filters 8R, 8G, and 8B is provided a black matrix 8BM. The black matrix 8BM functions as a light absorbing layer for absorbing light which is incident from other pixels, as will be described later in a Second Embodiment.

[0034]

The retro-reflector 9 is used for retro-reflecting an incident ray from the incident substrate 6. The retro-reflector 9 is in the form of a corner cube array, and includes a black resin layer 9a, a silver thin film 9b

serving as a reflecting surface, and a plurality of corner cubes 9c. The silver thin film 9b is arranged on the black resin layer 9a, and the corner cubes 9c are arranged on the silver thin film 9b.

[0035]

In the retro-reflector 9, each corner cube 9c of the corner cube array is a unit structure, i.e. reflection unit. Further, each corner cube 9c has a light absorbing surface 9d. That is, the light absorbing surface 9d is realized by a plane of the corner cube 9c (unit structure).

[0036]

The corner cube array has a characteristic of causing a parallel displacement of a light beam symmetrically with respect to a central axis, in addition to the characteristic of retro-reflecting the incident ray back to the direction of incidence. That is, as shown in Fig. 1, the path of an outgoing ray (reflected light) 12 is in near symmetry with that of an incident ray 10 about a central axis 13.

[0037]

In the reflective liquid crystal display device 10 of the present embodiment, the pitch of the unit structures (i.e., the corner cubes 9c) of the retro-reflector 9 is set to be not more than the pitch of the color filters 8R, 8G, and 8B. Here, the pitch of the corner cubes 9c is the shortest

distance between corresponding positions of adjacent corner cubes 9c (e.g., between vertices of the corner cubes) (indicated by pitch 22 in Fig. 3(b), Fig. 4(f) and Fig. 5(a)). Further, the pitch of the color filters 8R, 8G, and 8B is the shortest distance between corresponding positions of adjacent color filters 8R, 8G, and 8B (e.g., between centers of the color filters)(indicated by pitch 28 in Fig. 1).

[0038]

In the reflective liquid crystal display device 10, because the pitch 22 of the corner cubes 9c of the retro-reflector 9 is related to the pitch 28 of the color filters 8R, 8G, and 8B in the foregoing manner, the light incident on the retro-reflector 9 through any color filter 8R, 8G, or 8B is reflected by the retro-reflector 9 and outgoes from the device by passing through the same color filter 8R, 8G, or 8B. Therefore, the problem of the incident ray and the outgoing ray passing through different color filters 8R, 8G, and 8B is avoided, thereby preventing reduction in luminance and chromaticity due to mixed colors.

[0039]

The following explains display operation of the reflective liquid crystal display devices 10.

[0040]

As previously described, the liquid crystal layer 1 of the reflective liquid crystal display device 10 is in the scattering state under applied voltage, and is in the transmissive state under no applied voltage. The incident ray on the liquid crystal layer 1 is modulated depending on whether the liquid crystal layer 1 is in the scattering state or in the transmissive state.

[0041]

First, an operation of white state will be described. Under applied voltage, when light is incident on the liquid crystal layer 1 in the scattering state, the steering light and forward scattered light through the liquid crystal layer 1 are reflected at the retro-reflector 9 and then scattered as they again pass through the liquid crystal layer 1 in the scattering state, thereby returning more light, not only the backward scattered light, to the viewer (observer). That is, in addition to the inefficient backward scattered light, the forward scattered light passing through the liquid crystal layer 1 are used, thus obtaining highly bright display.

[0042]

The following explains an operation of a black state. Under no applied voltage, the liquid crystal layer 1 is in the transmissive state. Tracing the light path onto an eye

of the observer of the display, the light is refracted by the incident substrate 6 and the liquid crystal layer 1, and after being reflected by the retro-reflector 8, it is refracted again by the incident substrate 6 and the liquid crystal layer 1 before it finally reaches an area in the vicinity of the observer's eye. That is, the outgoing ray which the observer sees is entirely the incident ray from the area in the vicinity of the observer's eye. Here, the black state is effected when the area in the vicinity of the observer's eye is sufficiently small to the extent where no light can make up a light source, e.g., smaller than the black part of the eye.

[0043]

The following explains a relation between the viewer and the retro-reflector 9 with reference to Fig. 3.

[0044]

As shown in Fig 3(a), when the observer is observing the center or near center (bottom area) of the corner cubes 9c of the retro-reflector9, the location of the light source of the observed light is in the very vicinity of the observer's eye. That is, in this case, the ray 16 which is incident on the reflective liquid crystal display device 10 from the very vicinity of the observer's eye is reflected by the retro-reflector9 and the observer sees the outgoing ray

17.

[0045]

Further, as shown in Fig. 3(b), when the observer is observing an upper end portion of the corner cube 9c of the retro-reflector 9, the location of the light source of the light which the observer sees is below the observer's eye. That is, in this case, a ray 18 which is incident on the reflective liquid crystal display device 10 from the area below the observer's eye is reflected by the retro-reflector and the observer sees an outgoing ray 19 of the reflected light. Here, when the pitch 22 of the corner cube 9c of the retro-reflector 9 is larger, the observer will see the bottom eyelid, or the cheeks depending on the pitch size.

[0046]

On the contrary, as shown in Fig. 3(b), when the observer is observing a lower end portion of the corner cubes 9c of the retro-reflector 9, the location of the light source of the light which the observer sees will be an area above the observer's eye. That is, in this case, a ray 20 which is incident on the reflective liquid crystal display device 10 from an area above the observer's eye is reflected by the retro-reflector 9 and the observer sees an outgoing ray 21 of the reflected light. Here, when the pitch 22 of the corner cubes 9c of the retro-reflector 9 is larger,

the observer will see the eyelid, or the eye brow.

[0047]

Note that, Fig. 3(c) shows an arrangement where a bead (micro sphere) 14 is used as the unit structure of the retro-reflector 9. As shown in this drawing, the relation between the observer and the reflected light from the retro-reflector 9 is also the same as the case of Fig. 3(b) which uses the corner cube 9c.

[0048]

Therefore, the image mirrored by the unit structure of the retro-reflector 9 has a length 50, which is two times a pitch 22 of the unit structure of the retro-reflector 9. That is, in order to realize a desirable black state, the image within a plane of the length 50, which is two times the pitch 22 of the smallest unit structure of the retro-reflector 9, needs to be smaller than the black part of the eye, and, considering that the size (diameter) of the black part of the eye is about 10 mm, it can be deduced that the pitch 22 of the unit structure of the retro-reflector 9 needs to be not more than 5 mm. This arrangement realizes the reflective display device 10 having a bright white state and a high contrast ratio.

[0049]

As described, in the reflective liquid crystal display

device 10 of the present embodiment, the pitch 22 of the corner cubes 9c of the retro-reflector 9 is not more than the pitch 28 of the color filters 8R, 8G, and 8B, and more specifically, the pitch 22 of the corner cubes 9c and the pitch 28 of the color filters 8R, 8G, and 8B are 25 μm and 100 μm , respectively.

[0050]

Therefore, as shown in Fig. 1, the reflected light 12 with respect to the incident ray 11 having passed through the color filter 8B passes through the same color filter 8B. That is, in the reflective liquid crystal display device 10, the light incident on the retro-reflector 9 through any color filter 8R, 8G, or 8B, reflected by the retro-reflector 9, outgoes from the device by passing through the same color filter 8R, 8G, or 8B.

[0051]

For comparison with the reflective liquid crystal display device, as shown in Fig. 7, a reflective liquid crystal display device 10 in which a pitch of corner cubes of a retro-reflector 38 is larger than a pitch of the color filters 8R, 8G, and 8B was prepared. Specifically, a pitch of the corner cubes of the retro-reflector 38 is 120 μm , and a pitch of the color filters 8R, 8G, and 8B is 100 μm .

[0052]

As shown in Fig. 7, in the reflective liquid crystal display device 42, reflected light 40 with respect to an incident ray 39 having passed through the color filter 8G passes through the color filter 8R, and thus the incident ray 39 and the outgoing ray 40 pass through different color filters 8G and 8R. As a result, luminance and chromaticity are reduced due to mixed colors.

[0053]

On the other hand, in the reflective liquid crystal display device 10 of the present embodiment, the pitch 22 of the corner cubes 9c of the retro-reflector 9 is not more than the pitch 28 of the color filters 8R, 8G, and 8B, and therefore the problem of the incident ray and the outgoing ray passing through different color filters 8R, 8G, and 8B is not posed, thus preventing reduction in luminance and chromaticity due to mixed colors.

[0054]

Next explained is a production steps using the lift-off method, with reference to Fig. 4.

[0055]

First, a black acrylic resin is press molded using a mold, so as to make a bottom shape 23 (the black resin layer 9a in Fig. 1) of the corner cubes 9c (see Fig. 4(a)). Thereafter, a resist 24 is applied by the screen printing

method. The resist 26 is made of, for example, the material OFPR-800 (provided by Tokyo Ohka Kogyo Co., Ltd.), and is deposited to a thickness of 4 μm (see Fig. 7(b)).

[0056]

Then, the resist 24 is pre-baked at 100°C for 30 minutes, and a photomask 25 is placed on the resist 24 for exposure (see Fig. 4(c)). The photomask 25 may have a pattern shown in Fig. 5(a) or a pattern shown in Fig. 5(b). The pattern shown in Fig. 5(a) is such that the corner cubes 9c are parted. With this pattern, as previously described, the light absorbing surface 9d can be realized by a plane of the corner cubes 9c. Further, the pattern shown in Fig. 5(b) is such that the corner cubes 9c are further parted. With this pattern, the light absorbing surface 9d can be realized by a plane of the corner cubes 9c, and it is possible to realize an arrangement in which the light absorbing sections are arranged on the vertices and the sides (edges) of the respective corner cubes 9c.

[0057]

After the exposure, the resist 24 is developed and silver is deposited on the reflection surface in the normal direction of the substrate to a thickness of 2000 Å, so as to form a silver thin film 9b (see Fig. 4(d)). The developer

may be, for example, the NMD-32.38 % (provided by Tokyo Ohka Kogyo Co., Ltd..

[0058]

Then, the resist 24 is detached (Fig. 4(e)). Finally, the retro-reflector 9 is completed by planarizing it with a transparent resin 27 (Fig. 4(f)).

[0059]

Note that, the retro-reflector 9 may be integrally formed with the reflection substrate 7 by the foregoing method.

[0060]

That is, when the photomask 25 has the pattern as shown in Fig. 5(a), the light absorbing surface 9d can be formed at some of the planes making up the corner cube 9c. Therefore, with the foregoing arrangements, it is possible to obtain the reflective liquid crystal display device 10 which prevents deterioration in the black state and which has a high contrast ratio. Further, when the photomask 25 has the pattern as shown in Fig. 5(b), it is possible to realize a structure in which the light absorbing sites are provided for the vertices and sides of the corner cube 9c. Therefore, with the foregoing arrangements, it is possible to obtain the reflective liquid crystal display device 10 which prevents reflections at the vertices or

sides and which has a high contrast ratio.

[0061]

Although the foregoing method is a lift-off method, it is possible to produce the retro-reflector 9 by a conventional method in which a metal such as silver or aluminum is patterned after deposited by evaporation, and patterned.

[0062]

As described, the liquid crystal layer 1 of the reflective liquid crystal display device 10 is a polymer-dispersed-type liquid crystal, which is one form of light scattering liquid crystal. The polymer-dispersed-liquid crystal is obtained by placing a uniform mixture of a low-molecular-weight liquid crystal composition and pre-polymer between the substrates 6 and 7, and by polymerizing the pre-polymer therein. As long as the polymer-dispersed-liquid crystal is obtained by polymerization, type of the polymer-dispersed-liquid crystal is not limited.

[0063]

The present embodiment uses a cured material (UV light curable liquid crystal). This cured material is obtained by exposing a mixture of a UV curable liquid crystal prepolymer and a liquid crystal composition to an

activation light such as UV light. By using the UV light curable liquid crystal as the polymer-dispersed-liquid crystal, a heating is not required when polymerizing a polymer liquid crystal, and damages to other members can be prevented.

[0064]

For example, it is possible to adopt a prepolymer liquid crystal composition, showing a nematic crystal phase at room temperature. The polymer liquid crystal composition is produced by adding a small amount of polymerization initiator (product name: Irgacure 651, provided by Cibageigy) to a mixture of the UV curable liquid crystal prepolymer and a liquid crystal (product name TL213 of Merck & Co., Inc.; $\Delta n = 0.238$) at the weight ratio of 20:80.

[0065]

As described, the present embodiment uses the polymer-dispersed-liquid crystal as the liquid crystal layer 1. However, the present invention is not limited to this, and a similar result can be obtained by adopting any of the following liquid crystal layer 1.

[0066]

Namely, other than the polymer-dispersed-type liquid crystal, the light scattering liquid crystal may be a

nematic-cholesteric phase transition liquid crystal, a liquid crystal gel, or the like. Further, the liquid crystal layer 1 may be liquid crystal whose mode is switched between the transmissive state and a state in which at least scattering effect is exhibited. For example, it is possible to employ a cholesteric liquid crystal which is rendered scattering by controlling the domain size, and which switches between the transmissive state and the reflecting state, or a polymer-dispersed-liquid crystal having the holographic function, which switches between the transmissive state and the reflecting state, and is rendered scattering by the exposure of scattered light.

[0067]

Further, the present embodiment deals with the reflective liquid crystal display device 10. However, the present invention is also applicable to reflective display devices other than the reflective liquid crystal display devices (e.g., flat-panel display device which is switched between a transmissive state and a scattered state).

[0068]

In the reflective liquid crystal display device 10 of the present embodiment, the retro-reflector 9 adopts the corner cube arrays having a plurality of the corner cubes 9c. However, not limiting to this, it is also possible, as

shown in Fig. 2, to provide a reflective liquid crystal display device 15 having a plurality of beads (micro spheres) 14.

[0069]

In the reflective liquid crystal display device 15, each bead 14 makes up the unit structure of the retro-reflector 9, and the pitch 51 of the beads 14 of the retro-reflector 9 is not more than the pitch 28 of the color filters 8R, 8G, and 8B. Specifically, the pitch 51 of the beads 14 and a pitch 28 of the color filters 8R, 8G, and 8B are 25 μm and 100 μm , respectively.

[0070]

Thus, as shown in Fig. 2, the reflected light 12 with respect to the incident ray 11 having passed through the color filter 8B passed through the same color filter 8B. That is, in the reflective liquid crystal display device 15, the light incident on the retro-reflector 9 through any color filter 8R, 8G, or 8B, reflected by the retro-reflector 9, outgoes from the device by passing through the same color filter 8R, 8G, or 8B.

[0071]

For comparison with the reflective liquid crystal display device 15, as shown in Fig. 8, a reflective liquid crystal display device 47 in which a pitch of beads of a

retro-reflector 43 is larger than a pitch of the color filters 8R, 8G, and 8B was prepared. Specifically, a pitch of the beads of the retro-reflector 43 is 120 μm , and a pitch of the color filters 8R, 8G, and 8B is 100 μm .

[0072]

As shown in Fig. 8, in the reflective liquid crystal display device 47, reflected light 45 with respect to an incident ray 44 having passed through the color filter 8G passes through the color filter 8R, and thus the incident ray 44 and the outgoing ray 45 pass through different color filters 8G and 8R. As a result, luminance and chromaticity are reduced due to mixed colors.

[0073]

On the other hand, in the reflective liquid crystal display device 15 of the present embodiment, the pitch 51 of the beads 14 of the retro-reflector 9 is not more than the pitch 28 of the color filters 8R, 8G, and 8B, and therefore the problem of the incident ray and the outgoing ray passing through different color filters 8R, 8G, and 8B is not posed, thus preventing reduction in luminance and chromaticity due to mixed colors.

[0074]

Further, the retro-reflector 9 may have an arrangement, other than the corner cube array or bead

array, employing a micro lens array which is made up of a plurality of micro lenses. The retro-reflector 9 may use any reflecting material as long as it has the characteristic of retro-reflecting incident light back to the direction of incidence, and the characteristic of causing a parallel displacement of a light beam symmetrically with respect to a central axis.

[0075]

It is also possible to have an arrangement, as shown in Fig. 6, wherein a lens sheet 52 is provided more toward the incident side than the retro-reflector 9. This improves the retro-reflectivity of the retro-reflector 9, which makes it possible to realize a reflective liquid crystal display device capable of a bright white state and having a high contrast ratio. Note that, the lens sheet 52 is provided on the surface (front surface) of the incident substrate 6 in the arrangement of Fig. 6, but the lens sheet 52 may alternatively be provided directly on the retro-reflector 9.

[0076]

Further, the present embodiment used the alignment films 2 and 3 as the planar alignment film. However, the present invention is not limited to this, and any types of alignment films may be used.

[0077]

[Second Embodiment]

The following will describe another Embodiment of the present invention with reference to Fig. 9 through Fig. 11. Note that, elements having the same functions as those described in the drawings of the foregoing First Embodiment are given the same reference numerals and explanations thereof are omitted here.

[0078]

As shown in Fig. 9, a reflective liquid crystal display device 31 of the present embodiment differs from the reflective liquid crystal display device 10 of the First Embodiment in that the incident substrate 6 is provided with a plurality of louvers (light absorbing layer) 30. The other arrangement is the same as that of the reflective liquid crystal display device 10.

[0079]

The louvers 30 are essentially a light absorbing layer which absorbs light which are incident from different pixels, and the louvers 30 are a light-shielding element for shielding light within a predetermined range.

[0080]

As shown in Fig. 9, in the reflective liquid crystal display device 31 there are cases where a part of incident light on pixels in a white state, i.e., in a scattering state,

is incident as stray light 29 on other pixels in a black state, i.e., in a transmissive state.

[0081]

In the reflective liquid crystal display device 31, by the provision of the louvers 30, the stray light 29 from the other pixels can be absorbed by the louvers 30.

[0082]

In a reflective liquid crystal display device 49 having no louvers, as shown in Fig. 11, when the ray 48 from other pixels is incident on the black state pixel, i.e., on pixels in a transmissive state, the travelling direction of the light beam is deflected by the retro-reflector 9 of the corresponding pixel and the light outgoes from the liquid crystal panel. This increases reflectance of the black state and causes deterioration of the black state.

[0083]

In contrast, in the reflective liquid crystal display device 31 of the present embodiment, the ray of light 29 from other pixels can be absorbed by the louvers 30, thus suppressing increase in reflectance of the black state in a viewing direction, and thus realizing a desirable black state. This effect is especially notable when the retro-reflector 9 employs the corner cube array.

[0084]

The foregoing effect can also be realized by the arrangement of the reflective liquid crystal display device 10 of the Third Embodiment as shown in Fig. 10 in which The color filter layer 8 serves as the light absorbing layer. That is, the stray light 32 from other pixels is absorbed by the black matrix 8BM, and sufficiently reduced essentially by passing through the plurality of color filters 8R, 8G, and 8B, thus maintaining a desirable black state.

[0085]

As described, by providing the light absorbing layers such as the louvers 30 and/or the color filter layer 8, increase in reflectance of the black state in the viewing direction can be suppressed and a desirable black state can be realized.

[0086]

[Third Embodiment]

The following will describe yet another Embodiment of the present invention with reference to Fig. 12. Note that, elements having the same functions as those described in the drawings of the foregoing First Embodiment are given the same reference numerals and explanations thereof are omitted here.

[0087]

As shown in Fig. 12, a reflective liquid crystal

display device 37 of the present embodiment differs from the reflective liquid crystal display device 10 of the First Embodiment in a light absorbing element 34 which covers a side surface of a liquid crystal panel making up a display panel (particularly, side surface of the liquid crystal layer 1). The other arrangement is the same as that of the reflective liquid crystal display device 10.

[0088]

As shown in Fig. 12, the reflective liquid crystal display device 37, by the provision of the light absorbing element 34, prevents entry of external light 35 into the liquid crystal panel. Further, adverse effects of black state, which result from scattering of the ray 36 reaching a side surface of the liquid crystal panel by travelling inside the device, can be prevented, thus realizing a desirable black state.

[0089]

Note that, the light absorbing element 34 is preferably provided on all four sides of the liquid crystal panel.

[0090]

Further, the material of the light absorbing element 34 is not particularly limited but the same material as that of the louver 30 or the black matrix 8BM can be

used.

[0091]

[EFFECTS OF THE INVENTION]

In a reflective display device of the present invention thus described, a pitch of unit structures of the retro-reflector is not more than a pitch of color filters.

[0092]

Therefore the problem of the incident ray and the outgoing ray passing through different color filters is solved, Thus a reduction in luminance and chromaticity due to mixed colors are prevented.

[0093]

Further, with the arrangement in which the incident ray from other pixels is absorbed by the light absorbing layer such as the louvers or color filters, increase in reflectance of the black state in the viewing direction is suppressed, thereby realizing a desirable black state.

[0094]

Further, by such an arrangement in which the light absorbing element covers a side surface of the display panel, entry of external light into the display panel is prevented. This arrangement also prevents adverse effects of black state, which result from scattering of light reaching the side surface by travelling inside the device,

thus realizing a desirable black state.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

A cross sectional view showing schematic configuration of a reflective display device of an embodiment.

[Fig. 2]

A cross sectional view showing schematic configuration of a modification example of the reflective display device, in which unit structures of retro-reflector adopt beads.

[Fig. 3]

(a) through (c) are explanatory diagrams showing a light path of an outgoing ray incident on a retro-reflector of the reflective display device.

[Fig. 4]

(a) through (f) are cross sectional views showing steps of producing the retro-reflector.

[Fig. 5]

(a) and (b) are explanatory diagrams showing a pattern of a photomask used in the foregoing steps of production.

[Fig. 6]

A cross sectional view showing a schematic

configuration of a modification example of the reflective display device, in which a lens sheet is provided on an incident side of the retro-reflector.

[Fig. 7]

A cross sectional view showing a schematic configuration of a conventional reflective display device.

[Fig. 8]

A cross sectional view showing a schematic configuration of a conventional reflective display device.

[Fig. 9]

A cross sectional view showing a schematic configuration of a reflective display device of another embodiment.

[Fig. 10]

A cross sectional view showing a schematic configuration in which a light absorbing layer employs color filters.

[Fig. 11]

A cross sectional view showing a schematic configuration of a conventional reflective display device.

[Fig. 12]

A cross sectional view showing a schematic configuration of a reflective display device of yet another embodiment.

[REFERENCE NUMERALS]

- 1 Liquid crystal layer (middle layer)
- 2, 3 Alignment films
- 4, 5 Electrodes
- 6 Incident substrate (a pair of substrates)
- 7 Reflection substrate (a pair of substrates)
- 8 Color filter layer (light absorbing layer)
- 8R, 8G, 8B Color filters
- 8BM Black matrix
- 9 Retro-reflector
- 9c Corner cubes (unit structures)
- 10 Reflective liquid crystal display device
- 22 Pitch of corner cubes
- 28 Pitch of color filters
- 30 Louver (light absorbing layer)
- 34 Light absorbing element

[TITLE OF THE DOCUMENT] ABSTRACT

[ABSTRACT]

[OBJECT] To provide a reflective display device which is capable of clear multi-color display with a bright white state and a high contrast ratio, in which a reduction in luminance and chromaticity due to mixed colors are prevented.

[MEANS TO ACHIEVE THE OBJECT] A reflective display device 10 has a pair of substrates 6 and 7, a liquid crystal layer 1 arranged between the pair of substrates 6 and 7, and a retro-reflector 9. In the reflective display device 10, a pitch of corner cubes 9c of the retro-reflector 9 is not more than a pitch 28 of color filters 8R, 8G, and 8B.

[SELECTED DRAWINGS] Fig. 1